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Purification and utilization of garlic processing wastewater in lotus pond wetlands

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Abstract: Based on the experiments of utilization of garlic processing wastewater in a lotus pond, this study demonstrates that lotus pond wetlands have a remarkable ability to remove organic pollutants and decrease chemical oxygen demand (COD_{Cr}), biochemical oxygen demand (BOD_5), and suspended substances (SS) in garlic processing wastewater. Results also show evident effects of lotus roots on absorption of NH_3-N. The pH value in a lotus pond with wastewater discharged was relatively stable. The water quality in the lotus pond reached the class II emission standard, according to the *Integrated Wastewater Discharge Standard* (GB8978-1996), seven days after pretreated garlic processing wastewater had been discharged into the lotus pond. Garlic processing wastewater irrigation does not produce pollution in the pond sediment and has no negative effect on the growth of lotus roots. Due to utilization of garlic processing wastewater, the output of lotus roots increased by 3.0% to 8.3%, and the quality of lotus roots was improved. Therefore, better purification and utilization results can be achieved.

Key words: *lotus pond wetland; garlic processing wastewater; ecological treatment; removal rate; purification and utilization*

1 Introduction

The rapid development of agriculture and byproduct processing industries in China has resulted in increasingly serious environmental pollution (Ma 2006). Large amounts of organic matter are produced in agricultural byproduct processing wastewater, causing ecological environmental problems if these wastes are directly discharged into ditches and rivers (Wang et al. 2010). Severe water pollution can disrupt a river ecosystem and thus eradicate fish and shrimp. Pollution caused by agricultural byproduct processing wastewater has become one of the main factors restricting the development of ecological agriculture. With rapid socio-economic development, increasing water consumption leads to substantially increased sewage and wastewater, causing a severe imbalance between supply and demand of water

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resources and serious environmental pollution (Pang et al. 2009; Li et al. 2008a).

Wastewater recycling has been investigated and practiced, and experts in this field have made some achievements. Li et al. (2006) treated soybean processing wastewater with a two-stage anaerobic biofilter combined with a biological aerated filter (BAF), and the results showed that the chemical oxygen demand (COD) concentration was reduced from 4×10^4 mg/L to 118 mg/L. Teng and Wang (2005) studied the treatment of wastewater from frozen food processing by combining air floatation with bio-contact oxidation, and a COD removal rate of more than 97% was achieved in the effluent. Zhou et al. (2011) studied the utilization of potato starch wastewater using a modified nano-clay surfactant, and satisfactory results were obtained. Zhang et al. (2006) applied the process of pre-aeration treatment/air floatation/bio-contact oxidation in treatment of food processing wastewater, and the results showed that the water quality of the effluent could reach the class I emission standard according to the *Integrated Wastewater Discharge Standard* (GB8978-1996). Hu and Wang (2009) carried out experiments on treatment of dehydrated vegetable processing wastewater with the sequencing batch reactor (SBR) process, and the removal rates of COD, BOD_5 and SS reached 93.07%, 95.69%, and 89.11%, respectively. Zhao et al. (2008) studied the deodorization of dehydrated onion processing wastewater using modified organo-attapulgite, and also achieved satisfactory results. Liu et al. (2009) treated cassava processing wastewater using the two-stage BAF at the laboratory scale, and the average removal rates of COD and total nitrogen (TN) were 92.40% and 94.01%, respectively. Wang and Fan (2008) carried out an experiment on pretreatment of garlic processing wastewater using the micro electrolysis-contact oxidation process, and the COD concentration of the effluent after the whole process was less than 100 mg/L.

Because there are many types of agricultural byproduct processing wastewater with different levels of water quality (Zheng et al. 2003), it is necessary to study the methods of purification and utilization of agricultural processing wastewater corresponding to different levels of water quality. Based on experiments in a lotus pond wetland (Zhang 2011), this study examined the ecological treatment and utilization of garlic processing wastewater.

2 Methods

Garlic processing wastewater was produced by garlic washing and slicing. The wastewater pollution indicators were mainly composed of chemical oxygen demand (COD_{Cr}), biochemical oxygen demand (BOD_5), suspended substances (SS), and NH_3-N. Heavy metal ions and toxic substances were barely detected. Thus, garlic processing wastewater was classified as organic wastewater.

Alliinase is an enzyme found in garlic, converting alliin to garlicin during garlic processing. Diallyl sulfide with unique physiological activities is found in garlicin. An allyl group is a conjugated structural group. Electronegativity can provide sulfur atoms with electrons within the vicinity. Thus, electron-deficient sulfur diminishes as activity increases.

Then, garlicin was absorbed, forming high bio-activity sulfur groups, which can damage physiological processes such as protein synthesis (Li et al. 2008b). As a result, the biochemical treatment method is impaired. For this reason, pretreatment is necessary before wastewater is discharged into bio-treated units.

Ecological treatment and utilization of garlic processing wastewater are performed according to the following processes (Luo et al. 2012): (1) through filtration, sedimentation, pH value regulation, anaerobic treatment, and aeration, allicin molecules in wastewater are destroyed, and a simple wastewater pretreatment is accomplished; and (2) the pretreated wastewater is then discharged into the lotus pond wetland for ecological treatment and utilization.

2.1 Experiment design

A lotus pond, approximately 50 m from a small-scale vegetable dehydration processing plant, located in Bahu Town, Linyi City, in Shandong Province, China, was selected as the testing pond. The testing pond is 28 m wide and 32 m long, and the plant produces about 10 m^3 of wastewater a day.

The testing pond was divided by masonry into eight small pools of equal size, i.e., pool A to pool H, as shown in Fig. 1. To sustain the growth of lotus roots, each of the eight rectangular testing pools contained 45 m^3 of original water in the initial state. The eight testing pools were divided into four groups, corresponding to four irrigation schemes, scheme 1 to scheme 4. To promptly realize the uniform distribution of wastewater, two testing pools were used in each irrigation scheme. The pretreated garlic processing wastewater was first stored in a pond with a volume of 70 m^3. In scheme 1, 5 m^3 of pretreated garlic processing wastewater were discharged into pools A and B on August 1, 9, and 17, 2009; in scheme 2, 7.5 m^3 of pretreated garlic processing wastewater were discharged into pools C and D on August 3 and 15, 2009; and in scheme 3, 10 m^3 of pretreated garlic processing wastewater were discharged into pools E and F on August 5, 2009. No wastewater was discharged into pools G and H in scheme 4. The experimental schemes are listed in Table 1.

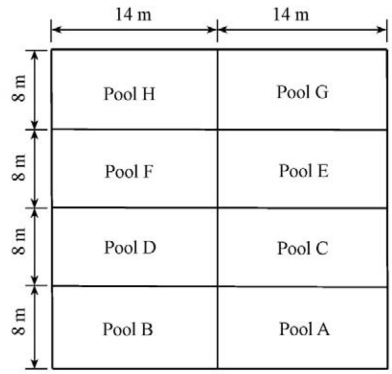

Fig. 1 Layout of testing pond

Table 1 Experimental schemes

Scheme	Pool	Wastewater irrigation	Discharged wastewater (m^3)	Irrigation time	Scheme	Pool	Wastewater irrigation	Discharged wastewater (m^3)	Irrigation time
1	A and B	Yes	5.0	3	3	E and F	Yes	10	1
2	C and D	Yes	7.5	2	4	G and H	No	0	0

2.2 Measurement

(1) The basic characteristics of sediments were detected, including the contents of organic

matter, N, P, and K and pH value in sediments. Three to five samples were obtained in diagonal corners of each testing pool for each time at the pre-planting, middle growth, and post-harvest stages of lotus root growth. Sediment samples were then detected in the laboratory after mixing.

(2) Water quality analysis of water samples was performed by tracking monitoring, which include the original wastewater, the wastewater after pretreatment, and the water sample in the lotus pond. The water sample in each testing pool needed to be examined daily under continuous operation. Three to five samples were taken in diagonal corners of each testing pool for each time and analyzed in the laboratory after mixing.

(3) Lotus root growth was investigated by recording the effective number of flowers, number of leaves, foliar diameter and petiole length of mature leaves, effective number of seedpods, lodging case, diseases, and insect pests.

(4) The effective yield of lotus roots in each testing pool was weighed and recorded in kg/hm^2.

(5) Based on stochastic sampling in different testing pools, the quality of lotus roots was evaluated and analyzed in the laboratory.

3 Result analysis and discussion

3.1 Water quality analysis

3.1.1 Water quality of garlic processing wastewater

The characteristics of garlic processing wastewater were investigated. Multi-sample inspection results showed that the amounts of main pollutants were relatively high, and the concentrations of COD_{Cr}, BOD_5, SS, and NH_3-N reached 6 500 to 8 100 mg/L, 3 500 to 5 000 mg/L, 1 000 to 1 500 mg/L, and 50 to 80 mg/L, respectively. Therefore, garlic processing wastewater directly discharged into the lotus pond would seriously affect the growth of lotus roots. To save costs and realize wastewater reutilization, we performed biological purification and utilization of garlic processing wastewater in the lotus pond after a simple pretreatment.

3.1.2 Water quality after pretreatment

The quality of garlic processing wastewater after pretreatment was monitored. It was found that the concentrations of COD_{Cr}, BOD_5, and SS were obviously degraded, with the values decreasing to a range of 3200 to 3800 mg/L for COD_{Cr}, 1900 to 2600 mg/L for BOD_5, and 150 to 350 mg/L for SS; that the pH value ranged in a stable manner from 6.1 to 7.4; and that the concentration of NH_3-N increased to a range of 114 to 200 mg/L. These values were favorable for the growth of lotus roots.

3.1.3 Water quality in lotus pond

The field study started in late July 2009. Sampling was performed using the three- or five-point method in each pool. Samples from two testing pools in each scheme were mixed and analyzed in the laboratory. The test results are shown in Fig. 2.

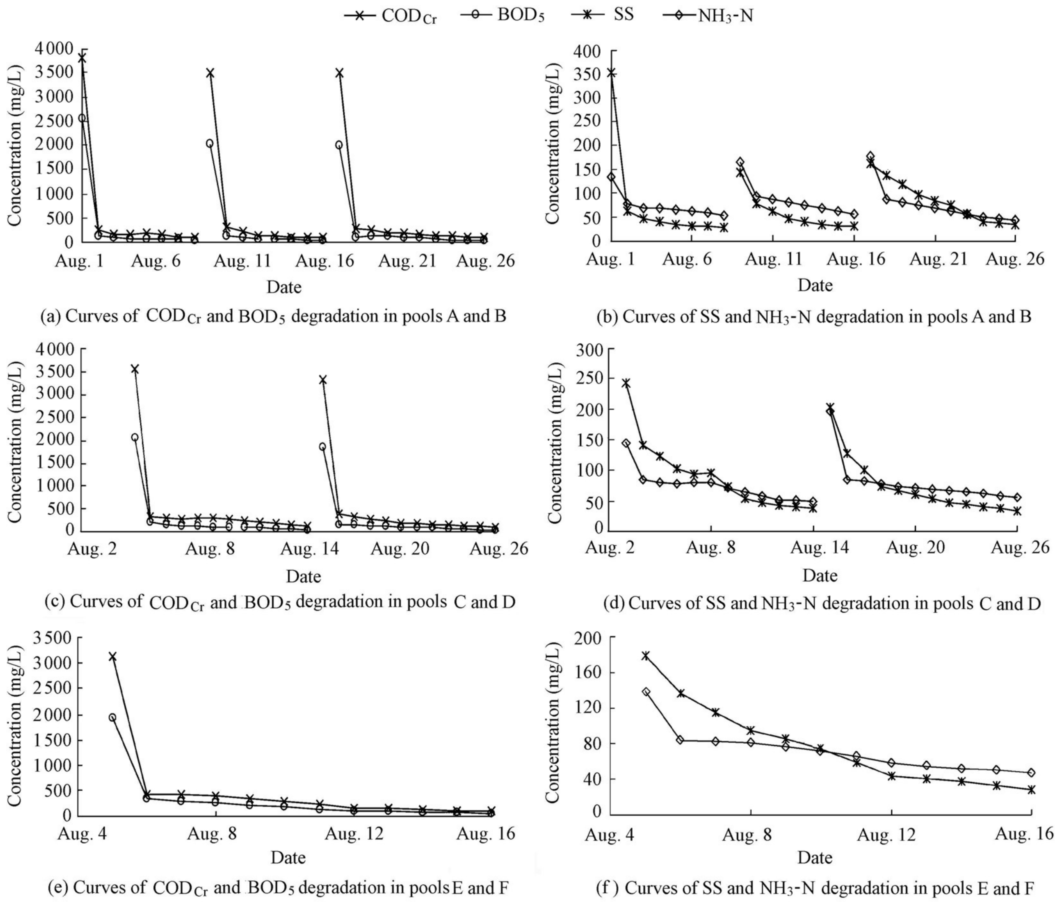

Fig. 2 Curves of COD_{Cr}, BOD_5, SS, and NH_3-N degradation

Fig. 2 shows the significant degradation of COD_{Cr}, BOD_5, and SS in testing pools after pretreated garlic processing wastewater was discharged in the lotus pond. The removal rates of COD_{Cr}, BOD_5, and SS exceeded 97%, 98%, and 80%, respectively. The water quality in the lotus pond with pretreated wastewater discharged could reach the class Ⅱ emission standard according to the *Integrated Wastewater Discharge Standard* (GB8978-1996) in about seven days. The lotus pond wetland can effectively remove NH_3-N by making use of it. In addition, the pH value was relatively stable, generally between 6.2 and 7.4, according to the monitoring data. Fig. 2 shows a slight difference between the three schemes. In contrast, the purification effects of scheme 1 (pools A and B) and scheme 2 (pools C and D) are better than that of scheme 3 (pools E and F). In general, multiple irrigation with little amount of wastewater and short time interval can quickly degrade wastewater.

3.2 Sediment analysis

3.2.1 Main sediment components

Mixed sediment samples from pools A to F were obtained at pre-planting, middle growth, and post-harvest stages of lotus root growth (labeled I, II, and III) in order to evaluate the influence of pretreated garlic processing wastewater discharged into the lotus pond on sediment. The samples were tested in the laboratory. Table 2 shows test results of 16 detection indicators.

Table 2 Chemical analysis of sediment samples

Stage	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)	Available Cu (mg/kg)	Available Zn (mg/kg)	Available Fe (mg/kg)	Available Mn (mg/kg)	Available B (mg/kg)
I	123.9	61.87	296.0	5.11	3.77	41.5	48.6	1.93
II	326.3	99.6	397.5	5.59	4.11	55.9	66.8	1.93
III	294.5	78.9	390.0	5.27	3.98	51.2	68.3	1.85
Stage	**Organic matter* (%)**	**TN (g/kg)**	**TP (g/kg)**	**Total Cu (mg/kg)**	**Total Zn (mg/kg)**	**Total Pb (mg/kg)**	**Total Cd (mg/kg)**	**pH value**
I	2.12	1.29	0.84	63.13	98.2	42.76	0.048	7.2
II	4.98	2.28	0.99	65.96	101.4	50.15	0.051	6.8
III	5.62	2.31	1.15	65.47	91.2	57.34	0.051	6.8

Note: * means the mass fraction.

3.2.2 Variations of main sediment components

(1) Changes in N, P, K, and organic matter in sediment: the available N, P, and K contents increased at first and then slightly decreased, but the organic matter in sediment increased throughout the study period. These results indicated that these nutrients were transformed after garlic processing wastewater was discharged into the lotus pond. The relatively high N, P, K, and organic matter contents increased the fertility of the pond sediment. As lotus roots absorbed these components for growth, the amounts of N, P, and K in sediment slightly decreased after lotus roots were harvested. The rates of absorption of N, P, and K by lotus roots were approximately 10%, 21%, and 2%, respectively.

(2) Changes in metal elements: no significant change was observed in available Cu, Zn, Fe, Mn, and B or in the total Cu, Zn, Pb, and Cd. The results show that garlic processing wastewater contains very few metal ions. Heavy metal pollution in sediment was not observed after garlic processing wastewater was discharged.

3.3 Growth status of lotus roots

From early August 2009, the growth status of lotus roots was monitored (Table 3). The results show that garlic processing wastewater after pretreatment, with high nutrient contents, is beneficial to the growth of lotus roots without adverse effects. Lotus roots are more vigorous with wastewater irrigation than without it. Moreover, garlic processing wastewater contributes to preventing insect pests from invading lotus roots.

3.4 Quality and yield of lotus roots

3.4.1 Quality of lotus roots

The components detected in lotus roots are listed in Tables 4 and 5. The nutrients in lotus roots reached a higher level. Harmful metal elements, such as Ni, Pb, Cr, Cd, As, and Hg, were not found. Lotus roots were within the range of edible safety standards.

Table 3 Growth status of lotus roots

Pool	Characteristic						
	Effective number of flower	Leaf number	Number of seedpod	Foliar diameter (cm)	Petiole length (cm)	Lodging	Disease and insect pest
A	117	1 340	112	55-62	100-115	Seldom	Without
B	120	1 380	118				
C	125	1 350	122				
D	123	1 440	108				
E	126	1 380	123				
F	125	1 430	120				
G	107	1 320	103	50-56	90-100	10%	Little
H	108	1 310	106				

Table 4 Contents of reducing sugar, amylum, total sugar, vitamin C, and water

Pool	Reducing sugar* (%)	Amylum* (%)	Total sugar* (%)	Vitamin C (mg/kg)	Water* (%)
A and B	1.85	18.31	1.95	34.6	77.46
C and D	1.79	16.25	1.76	35.6	78.06
E and F	1.86	16.56	1.97	34.3	78.52

Note: * means the mass fraction.

Table 5 Metal ion contents in dry samples of lotus roots

Pool	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)
A and B	15.10	5.46	14.00
C and D	18.23	6.32	11.45
E and F	13.89	5.78	12.35

3.4.2 Yield of lotus roots

The yield of lotus roots at harvest time was measured. Table 6 shows the measurement results. Timely and adequate irrigation of the lotus pond with pretreated garlic processing wastewater could increase the yield of lotus roots. The yield in pools C and D significantly increased at a rate of 8.3% as compared with that in pools G and H, which did not have wastewater irrigation. The yields in pools A and B and pools E and F increased by 3.8% and 3.0%, respectively. These results further demonstrate that high contents of nutrients in pretreated garlic processing wastewater are beneficial to improving soil fertility and growth of lotus, as well as increasing the yield of lotus roots and economic income in the farm, and the increase of yield changes with wastewater irrigation modes.

Table 6 Yields of lotus roots

Pool	Total output (kg)	Increasing rate (%)	Pool	Total output (kg)	Increasing rate (%)
A and B	524.24	3.8	E and F	519.88	3.0
C and D	546.97	8.3	G and H	504.85	

4 Conclusions

This study demonstrates that lotus pond wetlands can significantly degrade COD_{Cr}, BOD_5, SS, NH_3-N, and other pollutants and purify garlic processing wastewater without causing secondary pollution, and that garlic processing wastewater plays an effective role in the growth of lotus roots. Compared with the condition without wastewater irrigation, both the yield and quality of lotus roots significantly improve with wastewater discharge. It is suggested that lotus pond wetlands could be irrigated with a suitable volume of garlic processing wastewater in a timely manner to obtain the most efficient results. Comprehensive utilization of all lotus ponds, numbering nearly ten thousand in this area, will produce significant effects on wastewater treatment and utilization.

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